

PCTWORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁷ : B01J 35/00, 32/00, 21/06, 37/02, C02F 1/30	A1	(11) International Publication Number: WO 00/61290 (43) International Publication Date: 19 October 2000 (19.10.00)
(21) International Application Number: PCT/AU00/00313 (22) International Filing Date: 12 April 2000 (12.04.00) (30) Priority Data: PP 9722 13 April 1999 (13.04.99) AU (71) Applicant (for all designated States except US): UNISEARCH LIMITED [AU/AU]; Rupert Myers Building, Gate 14 Barker Street, UNSW, Sydney, NSW 2052 (AU). (72) Inventors; and (75) Inventors/Applicants (for US only): AMAL, Rose [AU/AU]; 24 Eucla Crescent, Malabar, NSW 2036 (AU). BEYDOUN, Donia [AU/AU]; 33 Caledonian Street, Bexley, NSW 2207 (AU). LOW, Gary [AU/AU]; 106/7-11 Gerrale Street, Cronulla, NSW 2230 (AU). MCEVOY, Stephen [AU/AU]; 8/77 Hawthorne Parade, Haberfield, NSW 2045 (AU). (74) Agent: GRIFFITH HACK; GPO Box 4164, Sydney, NSW 2001 (AU).		(81) Designated States: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>
(54) Title: A PHOTOCATALYST <p>(57) Abstract</p> <p>The present invention relates generally to a relatively stable magnetic photocatalyst comprising an insulated magnetite core coated with a layer of photoactive titanium dioxide. In one example the insulation layer is silicone dioxide which blocks direct electrical contact between the titanium dioxide and the magnetite.</p>		

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

A PHOTOCATALYST

FIELD OF THE INVENTION

5 The present invention relates generally to a photocatalyst and relates particularly, though not exclusively, to a photocatalyst suitable for use in a slurry-type photoreactor for degradation of organic compounds or chemicals such as but not restricted to those occurring in waste water effluents.

10

BACKGROUND TO THE INVENTION

Organic chemicals which may be found as pollutants in waste water effluents from industrial or domestic sources, must be removed or destroyed before discharge to the
15 environment. Such pollutants may also be found in ground and surface waters, which also require treatment to achieve acceptable drinking water quality. Much of the natural purification of aqueous system lagoons, ponds, streams, rivers and lakes is caused by sunlight initiating the
20 breakdown of organic molecules into simpler molecules and ultimately to carbon dioxide and other mineral products. There are various natural sensitizers that accelerate this natural purification process. The utilization of "colloidal semiconductors" and the introduction of
25 catalysts to promote specific redox processes on semiconductor surfaces has been under development since 1976. Laboratory studies have since confirmed that naturally occurring semiconductors enhance this solar driven purification process.

30

The photocatalytic detoxification or degradation of wastewater is a process that combines heterogeneous catalysis with solar technologies. Semiconductor photocatalysis, with a primary focus on titanium dioxide,
35 has been applied to a variety of problems of environmental interest in addition to water and air purification. The application of illuminated semiconductors for degrading

- 2 -

undesirable organics dissolved in air or water is well documented and has been successful for a wide variety of organic compounds. Organic compounds such as alcohols, carboxylic acids, amines, herbicides and aldehydes, have
5 been photocatalytically destroyed in laboratory and field studies. The solar photocatalytic process can also be applied to destroy nuisance odours, taste and odour compounds, and naturally occurring organic matter, which contains the precursors to trihalomethanes formed during
10 the chlorine disinfection step in drinking water treatment. It is thus generally recognised that the photocatalytic process can mineralise hazardous organic chemicals to carbon dioxide, water and simple mineral acids.

15 Many processes have been proposed over the years and are currently used to destroy organic toxins. Current treatment methods for destruction or degradation of these organic toxins, including adsorption by activated carbon and air stripping, merely concentrate the organics present
20 by transferring them to the adsorbent or air. However, these known treatment methods do not convert the organic toxins into non-toxic wastes. Thus, one of the major advantages of the photocatalytic process over these existing treatment methods is that there is no requirement
25 for further treatment or disposal methods. Another advantage of the photocatalytic process is that when compared to advanced oxidation technologies, especially those using oxidants such as hydrogen peroxide and ozone, expensive oxidising chemicals are not required as ambient
30 oxygen is the oxidant in the photocatalytic process. Photocatalysts are also self regenerated and can be reused or recycled.

It is understood that during the photocatalytic process the
35 illumination of a semiconductor photocatalyst with near ultraviolet radiation activates the photocatalyst establishing a redox environment in an aqueous solution.

- 3 -

Semiconductors act as sensitisers for light induced redox processes due to their electronic structure which is characterised by a filled valence band and an empty conduction band. The energy difference between the valence and conduction band is called the bandgap. Several semiconductors have band-gap energies sufficient for catalysing a wide range of chemical reactions. Titanium dioxide is the semiconductor most thoroughly investigated in the literature and is believed to be the most promising for photocatalytic destruction of organic chemicals. It is generally acknowledged that titanium dioxide provides the best compromise between catalytic performance and stability in an aqueous media.

15 In the photocatalytic detoxification or degradation of, for example, waste water, a large area of reactive photocatalyst surface is required for the large volume of water to be treated. Accordingly there is a need for submicron photocatalyst particles. Generally the photocatalytic reaction is conducted in a suspension of the insoluble semiconductor photocatalyst and, therefore, an additional separation step is required to remove the catalyst from the treated water. The removal of such fine photocatalyst particles from large volumes of water is difficult and involves additional expense in a continuous treatment process. In one reported study charge neutralisation, coagulation and flocculation was investigated as a basis for the enhanced settling and recycling of titanium dioxide in a suspended-photocatalyst system. Although relatively effective, such an approach includes the additional cost for chemicals and a requirement for critical process control. In addressing these problems, research has been carried out by immobilising titania onto various bearing materials, such as glass beads, sand, silica gel, quartz optical fibres, glass fibre in the form of mesh, or on a glass reactor wall. In this research the semiconductor photocatalyst is

- 4 -

fixed to a stationary illuminated support and waste water passed over or through the immobilised catalyst bed. This approach has the distinct disadvantage of greatly reducing the available surface area of the catalyst as well as
5 slowing down the photocatalytic reaction due to mass transfer limitations.

SUMMARY OF THE INVENTION

An intention of the present invention is to provide a
10 photocatalyst that is relatively effective in degrading organic compounds whilst being relatively stable.

According to one aspect of the present invention there is provided a photocatalyst comprising:

15 a core being at least partly formed of a magnetic material;

an insulative layer disposed about the core, the insulative layer being formed of an electrically non-conductive material; and

20 an outer layer disposed about the insulative layer, the outer layer being formed of a semi-conductor having photocatalytic properties.

According to another aspect of the present invention there
25 is provided a method of forming a photocatalyst comprising the steps of:

forming an insulative layer about a core which is at least partly formed of a magnetic material, the insulative layer being formed of an electrically non-conductive
30 material; and

forming an outer layer about the insulative layer, the outer layer being formed of a semi-conductor having photocatalytic properties.

35 Preferably the step of forming an insulative layer involves exposing the core to a reaction medium and adding appropriate reagents to precipitate the insulative layer on

- 5 -

the core. In one embodiment the step of forming a silica-based insulative layer involves suspending the core in a reaction medium of ethanol and adding aqueous tetraethoxysilane in the presence of ammonium hydroxide to precipitate silica on the core.

Alternatively the insulative layer and/or the outer layer may be formed by applying the Chemical Vapour Deposition (CVD) technique or by using Flame Aerosol Technology.

10

Typically the method of forming the photocatalyst further comprises the step of photodepositing a metal on the outer layer so as to enhance its photocatalytic properties. More typically the step of photodepositing the metal involves mixing the photocatalyst with a solution of metal ions and exposing the resultant suspension to natural or artificial radiation so as to reduce the metal ions and deposit them as the solid metal on the outer layer. In one embodiment the photocatalyst is mixed with a solution of silver nitrate.

20

According to a further aspect of the present invention there is provided a method of degrading organic compounds in an aqueous solution comprising the steps of:

25

providing a suspension of a photocatalyst in the aqueous solution, the photocatalyst comprising a core being at least partly formed of a magnetic material, an insulative layer disposed about the core, the insulative layer being formed of an electrically non-conductive material, and an outer layer disposed about the insulative layer, the outer layer being formed of a semi-conductor having photocatalytic properties;

30

exposing the aqueous solution together with the photocatalyst to natural or artificial radiation so as to promote the degradation of the organic compounds; and

35

promoting separation of the photocatalyst from the aqueous solution via magnetic separation of the catalyst.

- 6 -

Generally, the insulative layer is formed predominantly of silicon dioxide or silica or a derivative thereof. It is understood that the insulative layer prevents the contact of the magnetic core with the photocatalytic outer layer which ordinarily results in a photo-induced dissolution of the core.

Preferably the magnetic core is formed predominantly of iron oxide or a derivate thereof such as magnetite or maghemite.

Typically the photocatalytic outer layer is formed of titanium dioxide or titania (in the form of anatase crystalline phase) or a derivative thereof.

Preferably the photocatalyst further comprises a metal photodeposited on the outer layer so as to enhance its photocatalytic properties. More preferably the metal is silver. Additionally the metal includes but is not limited to copper or gold.

Generally the natural or artificial radiation is near ultra violet radiation having a wavelength less than 400nm.

Typically the outer layer is at least partly formed of titanium dioxide or titania in an anatase crystalline form or a derivative thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to achieve a better understanding of the nature of the present invention a preferred embodiment of a photocatalyst and a method of forming a photocatalyst will now be described in some detail, by way of example only, with reference to the accompanying graphs in which:

Figure 1 is a plot of carbon oxidised versus time for various catalysts according to embodiments of the invention

- 7 -

together with photocatalysts without an insulative intermediate layer and a single phase titanium dioxide photocatalyst;

5 Figure 2 is a bar graph of photocatalyst stability determined by measuring dissolved iron oxide for various embodiments of a photocatalyst according to the invention compared to photocatalysts without an insulative intermediate layer; and

10 Figure 3 is a schematic diagram of an experimental rig for the degradation of an organic compound in an aqueous solution using a photocatalyst according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

15 According to one embodiment of the invention there is provided a relatively stable magnetic photocatalyst comprising an insulated magnetite core coated with a layer of photoactive titanium dioxide. In this example the insulation layer is silicon dioxide which blocks direct
20 electrical contact between the titanium dioxide and the magnetite.

The photocatalyst is, according to one example prepared by firstly coating magnetite particles with a layer of silicon
25 dioxide. This is achieved by suspending the magnetite particles in a reaction medium, and adding reagents required to precipitate silicon dioxide onto the surface of the seed magnetite particles. In this example the reagents include tetraethoxysilane (TEOS) and water in the presence
30 of ammonium hydroxide and the reaction medium is ethanol. These insulated magnetite particles are then coated with a layer of titanium dioxide using the conventional sol-gel process. This involves deposition of a layer of titanium dioxide through hydrolysis and precipitation of titanium
35 butoxide onto the surface of the insulated magnetite particles which are suspended in the reaction medium. The coated particles in this example are then calcined at 450°C

- 8 -

or 550°C for a period of time transforming the amorphous TiO₂ to its anatase phase.

Various techniques may be used to coat the magnetic core and/or the insulative layer. For example by applying the Chemical Vapour Deposition (CVD) technique. This may be carried out in a fluidized-bed reactor (FBR). The sample to be coated is loaded as a powder in the FBR. The bed of particles is fluidized using a fluidizing gas in the form of an inert gas. The system is heated to operating temperature. Once fluidization is attained, precursors are introduced into the bed either by vapour addition to the fluidizing gas or by direct injection of liquid into the bed. This is followed by evaporation inside the reactor. On reacting, a coating is deposited onto the individual particles of the powdered material. An alternative technique to coat the core particles is by using the Flame Aerosol Technology. The sample to be coated is charged and dispersed as aerosol into the flame reactor. The insulative layer or silica coating could be formed from the combustion of a silicon precursor such as SiCl₄, while the photocatalytic layer or TiO₂ coating could be formed from the combustion of a titanium precursor such as TiCl₄.

It should be appreciated that the insulative layer is not restricted to silicone dioxide but rather extends to other electrically non-conductive materials such as aluminium oxide which preclude direct electrical contact between the magnetic core material and the photocatalytic outer layer. Further, the core may be formed of any suitable material which is magnetic and thus allows magnetic separation. The outer photocatalytic layer may be formed of practically any semi conductor which has photocatalytic properties suited to the detoxification or degradation of organic compounds in an aqueous solution.

- 9 -

The magnetite particles of this embodiment are thus electrically insulated from the photocatalytic outer layer via an intermediate silica layer. This does not adversely affect the intended function of the magnetite particles which are utilised for their magnetic properties to enhance settling rather than their electronic or optical properties. The insulative layer prevents the contact of the magnetic core with the photocatalytic outer layer, in this example the magnetite and titania respectively, which is understood as being the main cause for the photo-induced dissolution of the magnetite core as well as its low activity. The insulative layer should preferably be both chemically inert as well as electronically passive toward the photocatalytic outer layer. The coating of the insulative layer on the magnetic core should be dense enough to prevent the migration of electrons from the photocatalytic outer layer to the core.

The photocatalytic activity of various sample photocatalysts was tested in an aqueous solution of a model sucrose compound. The photocatalytic activity of each photocatalyst was assessed using a photocatalytic reaction system. The system included a photoreactor with a near-UV illumination source and a conductivity monitor for measuring carbon dioxide. An aliquot of the aqueous solution of the model sucrose compound was added to the system containing a suspension of the sample photocatalyst. By monitoring the rate of formation of carbon dioxide, the rate of mineralisation of the compound could be determined and compared directly with the rates obtained with other photocatalysts.

With reference to Figure 1 it is clear that the photocatalyst including an insulated magnetite core namely samples 3 and 4, according to one example of the invention outperformed all other samples tested. This included the pure titanium dioxide sample. The other comparative

- 10 -

samples 1 and 2, which did not include the insulation layer, exhibited a much lower photoactivity and suffered from a very high incidence of photodissolution.

5 Photodissolution tests were also conducted for the photocatalyst samples trialed in the preceding paragraphs. That is, comparative photodissolution tests were carried for photocatalyst samples including the insulation layer
10 around the magnetic core (samples 3 and 4), and those without the insulation layer (samples 1 and 2). The tests involved collecting the photocatalyst suspension after the photoreaction, that is after the suspension and circulated through the reactor, under near-UV illumination in the presence of sucrose under illumination for 30 minutes. The
15 pH of the suspensions was 3.5. The supernatant was collected through a 0.2- μ m micropore filter, and analysed for Fe ions using atomic absorption spectroscopy. It is clear from Figure 2 that the samples without the insulation layer suffered a tremendous degree of photodissolution
20 whereas those with the insulation layer were stable.

The magnetic photocatalyst described above was also used to oxidise methylene blue. A schematic diagram of the experimental rig 10 is shown in Figure 3. The rig 10
25 includes a photo-reactor 12 and magnetic separation unit 14 for recovery of the photocatalyst.

Initially, 100 mL of 1000 ppb of a methylene blue solution was mixed with 0.10 g of the magnetic photocatalyst to give
30 a catalyst loading of 0.5 g/L. This slurry was placed in an inlet reservoir 16. A peristaltic pump 18 then pumped the slurry through the photo-reactor 12 at ten (10) cc/min. Following oxidation, the treated slurry was passed through a separation channel of the magnetic separation unit 14
35 where the photo-catalyst was removed by a series of magnetic bars. The treated liquid was then pumped into an outlet reservoir 20.

- 11 -

Following treatment of the methylene blue solution and entrapment of the magnetic photo-catalyst in the separation channel, the magnetic bars were removed and the channel washed to recover the catalyst. The catalyst was recovered from the concentrated wash slurry by drying in an oven at 60°C. The methylene blue concentration in the inlet and outlet reservoirs was measured by UV-Spectrometry. The efficiency of the magnetic separation unit was measured by Turbidimetry. The flow-rate of the slurry through the system was 20 cc/min. The performance and recovery of the magnetic photo-catalyst was compared with a conventional Degussa (TiO₂) catalyst.

Table 1 lists the extent of methylene blue oxidation efficiency and the removal efficiency of the catalyst from the slurry.

Table 1: Oxidation efficiency and separation efficiency

Sample	Oxidation efficiency (%)	Separation efficiency (%)
Degussa P25/TiO ₂	99.6	0
Magnetic photocatalyst	97.3	95.8

Oxidation efficiency (%) =

$$(1 - \text{outlet methylene blue conc (ppb)} / 1000 \text{ (ppb)}) \times 100$$

Separation efficiency (%) =

$$(1 - \text{outlet turbidity (NTU)} / \text{inlet turbidity (NTU)}) \times 100$$

It is clear from this data that the magnetic photocatalyst achieved similar oxidation efficiencies to that of the conventional Degussa (TiO₂) catalyst. Relatively high separation efficiency was also obtained with the magnetic photocatalyst.

- 12 -

The applicant also intends to modify the photocatalyst with metal ion dopants including Cu(II), Ag(I) and Fe(III) so as to enhance its photocatalytic activity. It is envisaged that an appropriate amount of AgNO₃, Cu(NO₃)₂ and Fe(NO₃)₃ will be mixed with a suspension of the photocatalyst. The mixture can then be illuminated with near-ultraviolet radiation. The doped photocatalyst can then be used to degrade organic matter. It is to be understood that metal such as Ag ions will be deposited onto the photocatalyst as for example silver metal during the photo-oxidation of the organic matter.

It is to be understood that modification of the photocatalyst by the addition of metal dopants, for example AgNO₃, will enhance its photocatalytic activity.

Now that several preferred embodiments of the present invention have been described in some detail it will be apparent to those skilled in the art that the photocatalyst and method of forming a photocatalyst have at least the following advantages:

- (1) the photocatalyst is relatively stable in the aqueous solution containing the organic contaminants with minimal photo-induced dissolution of the magnetic core;
- (2) the photocatalyst incorporating a magnetic core lends itself to enhanced settling or separation via magnetic separation; and
- (3) the photocatalyst exhibits relatively high photo activity in its detoxification or degradation of organic compounds or chemicals in an aqueous solution.

Those skilled in the art will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described. For example, the magnetic core may be formed partially rather than wholly of a magnetic material provided the

- 13 -

photocatalyst of this example displays enhanced settling under a magnetic field.

5 All such variations and modifications are to be considered within the scope of the present invention the nature of which is to be determined from the foregoing description.

- 14 -

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A photocatalyst comprising:
a core being at least partly formed of a magnetic
5 material;
an insulative layer disposed about the core, the
insulative layer being formed of an electrically non-
conductive material; and
an outer layer disposed about the insulative layer,
10 the outer layer being formed of a semi-conductor having
photocatalytic properties.
2. A photocatalyst as defined in claim 1 wherein the
insulative layer is formed predominantly of silicon dioxide
15 or silica or a derivative thereof.
3. A photocatalyst as defined in claim 1 or 2 wherein
the magnetic core is formed predominantly of iron oxide or
a derivate thereof.
20
4. A photocatalyst as defined in any one of the
preceding claims wherein the photocatalytic outer layer is
formed of titanium dioxide or titania or a derivative
thereof.
25
5. A photocatalyst as defined in any one of the
preceding claims further comprising a metal photodeposited
on the outer layer so as to enhance its photocatalytic
properties.
30
6. A photocatalyst as defined in claim 5 wherein the
metal is silver.
7. A method of forming a photocatalyst comprising the
35 steps of:
forming an insulative layer about a core which is at
least partly formed of a magnetic material, the insulative

- 15 -

layer being formed of an electrically non-conductive material; and

forming an outer layer about the insulative layer, the outer layer being formed of a semi-conductor having
5 photocatalytic properties.

8. A method of forming a photocatalyst as defined in claim 7 wherein the step of forming an insulative layer involves exposing the core to a reaction medium and adding
10 appropriate reagents to precipitate the insulative layer on the core.

9. A method of forming a photocatalyst as defined in claim 7 wherein the insulative layer and/or the outer layer
15 may be formed by applying the Chemical Vapour Deposition (CVD) technique or by using Flame Aerosol Technology.

10. A method of forming a photocatalyst as defined in any one of claims 7 to 9 further comprising the step of
20 photodepositing a metal on the outer layer so as to enhance its photocatalytic properties.

11. A method of forming a photocatalyst as defined in claim 10 wherein the step of photodepositing the metal
25 involves mixing the photocatalyst with a solution of metal ions and exposing the resultant suspension to natural or artificial radiation so as to reduce the metal ions and deposit them as the solid metal on the outer layer.

30 12. A method of degrading organic compounds in an aqueous solution comprising the steps of:

providing a suspension of a photocatalyst in the aqueous solution, the photocatalyst comprising a core being at least partly formed of a magnetic material, an
35 insulative layer disposed about the core, the insulative layer being formed of an electrically non-conductive material, and an outer layer disposed about the insulative

- 16 -

layer, the outer layer being formed of a semi-conductor having photocatalytic properties;

5 exposing the aqueous solution together with the photocatalyst to natural or artificial radiation so as to promote the degradation of the organic compounds; and

promoting separation of the photocatalyst from the aqueous solution via magnetic separation of the catalyst.

10 13. A method of degrading organic compounds in an aqueous solution as defined in claim 12 wherein the natural or artificial radiation is near ultra violet radiation having a wavelength less than 400nm.

Results of Photocatalytic Activity Tests

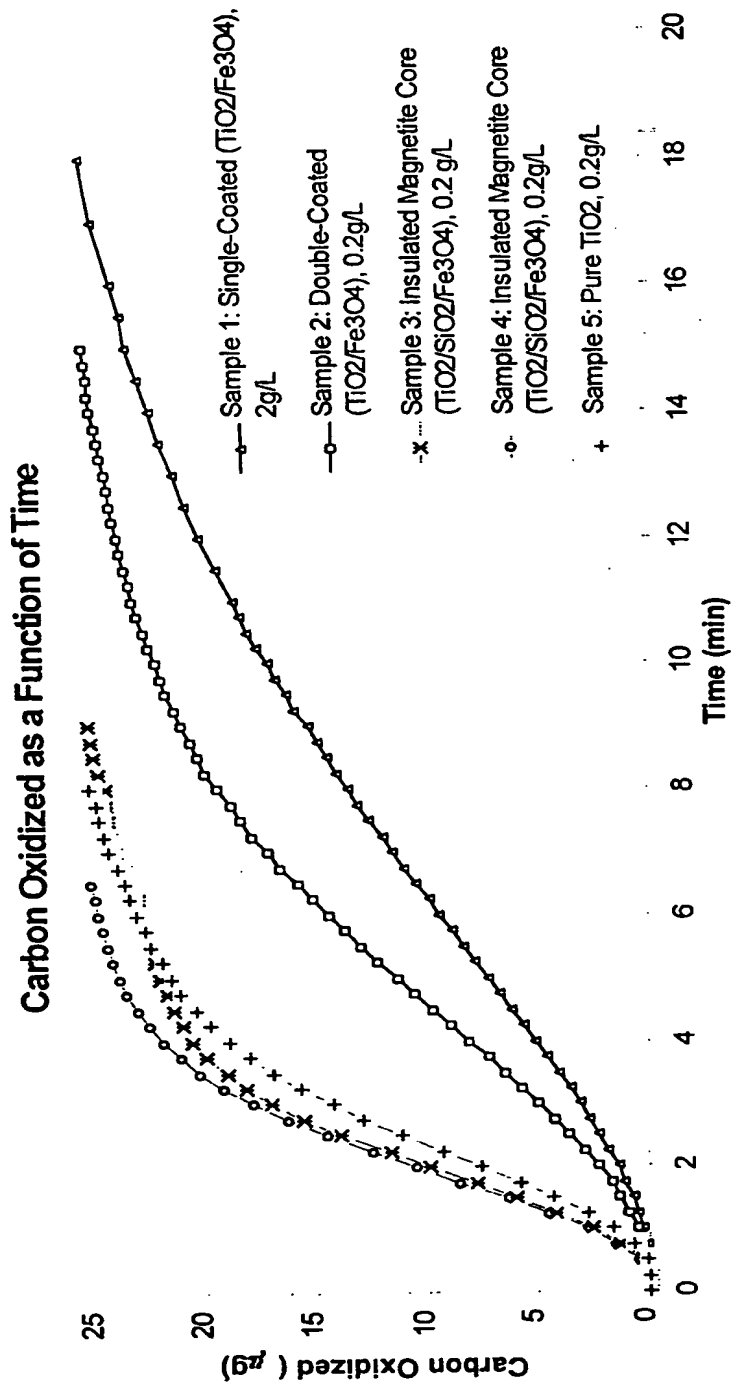


FIG. 1

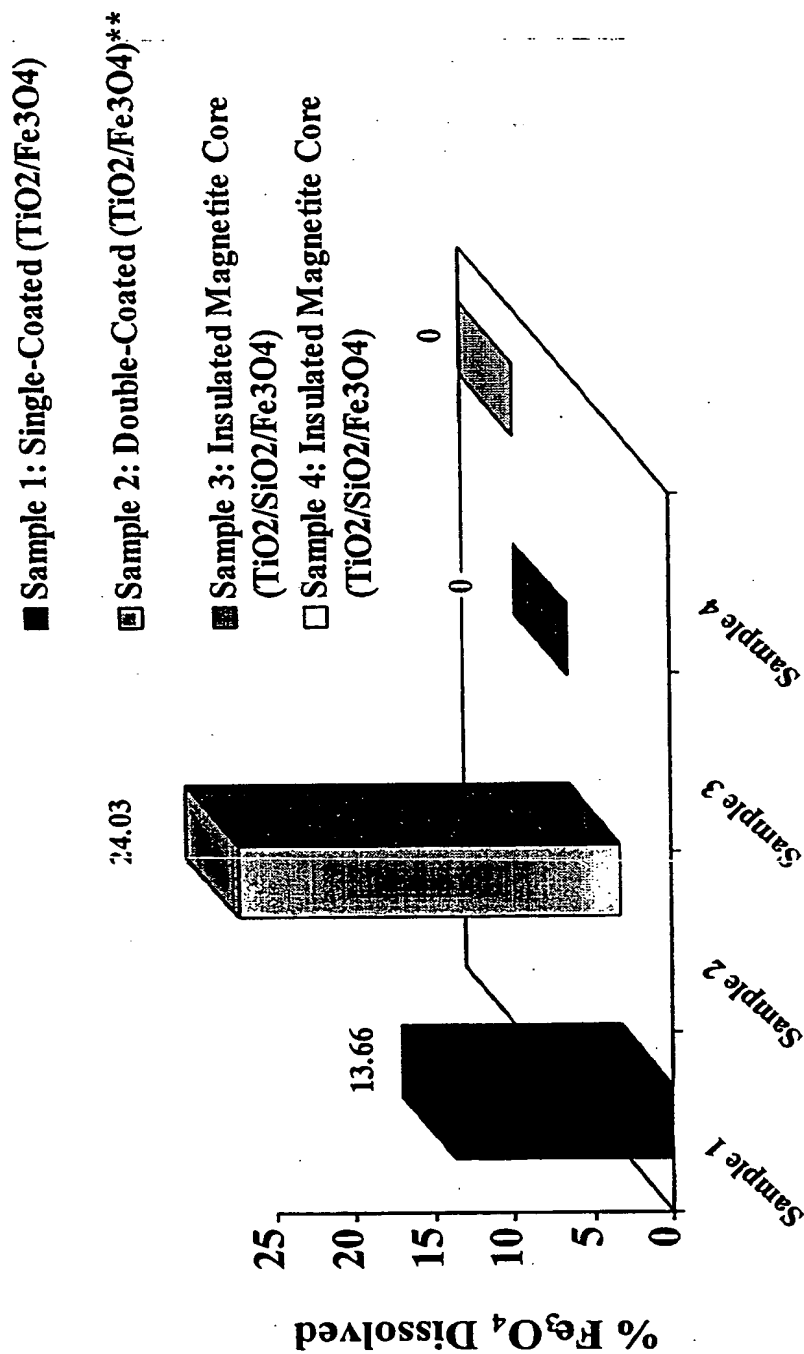


FIG. 2

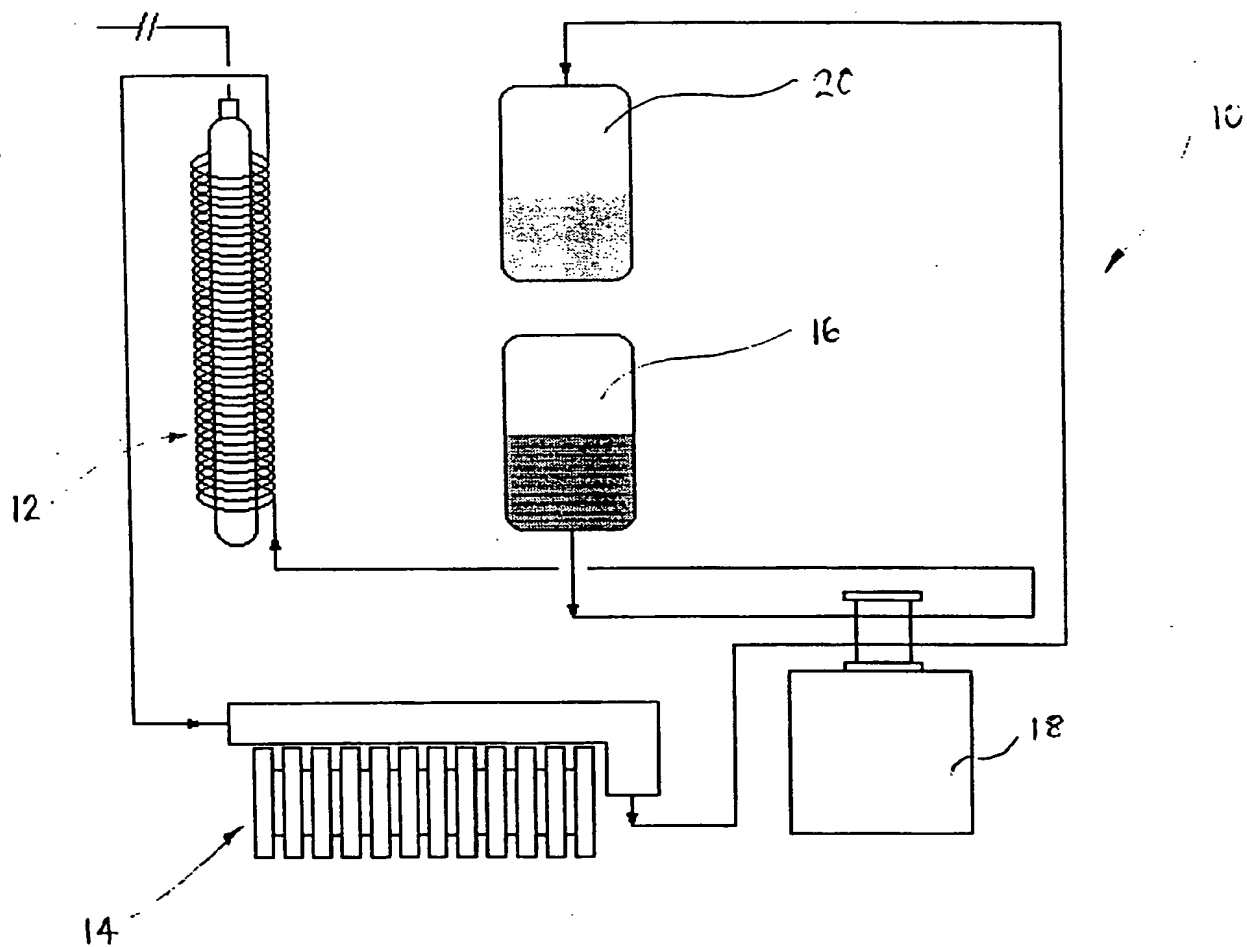
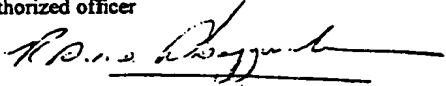


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 00/00313

A. CLASSIFICATION OF SUBJECT MATTER				
Int Cl ⁷ : B01J 35/00, 32/00, 21/06, 37/02; C02F 1/30				
According to International Patent Classification (IPC) or to both national classification and IPC				
B. FIELDS SEARCHED				
Minimum documentation searched (classification system followed by classification symbols) B01J 35/00, 32/00, 21/06, 37/02; C02F 1/30				
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched AU: IPC as above				
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) WPAT: MAGNET, TITAN				
C. DOCUMENTS CONSIDERED TO BE RELEVANT				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
A	US 5759948 A (YOICHI TAKAOKA et al) 2 June 1998			
A	US 5703002 A (ATSUYA TOWATA et al) 30 December 1997			
A	US 4861484 A (NORMAL N LICHTIN et al) 29 August 1989			
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C <input checked="" type="checkbox"/> See patent family annex				
<p>* Special categories of cited documents:</p> <table border="0"> <tr> <td style="vertical-align: top;"> <p>"A" Document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </td> <td style="vertical-align: top;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p> </td> </tr> </table>			<p>"A" Document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>
<p>"A" Document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>			
Date of the actual completion of the international search 12 May 2000		Date of mailing of the international search report 29 MAY 2000		
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200 WODEN ACT 2606 AUSTRALIA E-mail address: pct@ipaustalia.gov.au Facsimile No.: (02) 6285 3929		Authorized officer  ASOKA DIAS-ABEYGUNAWARDENA Telephone No.: (02) 6283 2141		

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 00/00313

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Derwent Abstract Accession No: 99-190917/17, Class D15, J04, CN 1200959 A (PHOTO-CHEMISTRY INST CHINESE ACAD SCI) 9 December 1998	
A	Derwent Abstract Accession No: 99-437889/37, Class D15, J04, JP 11-179212 A (TEI KOKU PISTON RING CO LTD) 6 July 1999	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/AU 00/00313

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
US	5759948	AU	11547/95	AU	70102/98	CA	2141921
		CN	1111546	EP	666107	JP	7303835
US	5703002	JP	9066237				
US	4861484	CA	1335581	EP	365615	GB	2225571
		WO	89/8079				
CN	1200959	NONE					
JP	11-179212	NONE					
							END OF ANNEX